NASA PROGRAM APOLLO WORKING PAPER NO. 1172

A TECHNIQUE FOR MONITORING THE PRIMARY GUIDANCE SYSTEM IN THE LEM-CSM RENDEZVOUS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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CONTENTS

FIGURES

A TECHNIQUE FOR MONITORING THE PRIMARY GUIDANCE SYSTEM IN THE LEM-CSM RENDEZVOUS

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SUMMARY

From an analysis of typical LEM-CSM rendezvous trajectories, a technique for monitoring the primary rendezvous guidance system has been established. The analysis includes intercept transfers and miss transfers in the case of terminal rendezvous not being initiated. It also includes the case of terminal rendezvous being initiated for each transfer by the primary rendezvous guidance system. The results of the analysis indicate that in both cases the relative range-rate is nearly constant during the terminal phase of the transfer with the exception of the miss transfers where terminal rendezvous is not initiated. Thus, in either a hard rendezvous (unguided intercept) or a soft rendezvous (guided intercept or guided miss) a common characteristic (constant range-rate) will occur which will not occur in the case of a miss trajectory where terminal rendezvous is not initiated. On this basis, the technique for monitoring the primary rendezvous guidance system is established. The technique consists of monitoring range and range-rate.

INTRODUCTION

The function of the automatic primary guidance system onboard the LEM is to provide the basic guidance for establishing the LEM on a collision course with the CSM, and to provide the guidance for performing the terminal rendezvous maneuver, that is, matching the terminal velocities in order to mate the spacecrafts (docking). It is desired to have some method of monitoring the primary system to detect failures. Then, if the rendezvous maneuver is to be performed by a technique other than the primary system, the pilot will have available a method of detecting errors in the primary system so that he can initiate corrective action. The purpose of this paper is to present a technique which the pilot can use to monitor the primary guidance system. More explicitly, the technique will monitor the accuracy of the intercept transfer and the accuracy with which the terminal rendezvous maneuver is executed by the primary system. The technique will enable the pilot to determine whether or not a change to an alternate rendezvous procedure is necessary.

ANALYSIS AND DISCUSSION

Rendezvous Procedure

The rendezvous procedure is illustrated in figure 1. Assuming the mission is completed, the LEM is launched (A-B) from the lunar surface into a parking orbit (B-C). At point C the primary guidance system will establish the LEM on an intercept transfer with the CSM. Finally, at point D, the primary system will provide the guidance for the terminal rendezvous maneuver. Any rendezvous from a mission abort would be encompassed by this procedure since the rendezvous maneuver as such begins at point C.

Characteristics of Intercept Trajectories

In order to formulate a workable monitoring technique, the characteristics of the intercept trajectories must first be discussed. When the primary guidance system establishes the LEM on a collision course with the CSM (point C, fig. 1) intercept trajectories such as those illustrated in figure 2 will result. Relative range rate is shown as a function of range for typical trajectories. The trajectories shown are those which may be encountered in either a completed LEM mission or an abort any time after LEM-CSM separation. The relative range, relative range-rate profiles in the figure indicate that at some range prior to intercept the relative range-rate becomes nearly constant for each trajectory. The range at which the range rate becomes constant depends upon the altitude difference over which the transfer is made. For the 50 000-ft to 80 nautical mile transfers shown the range rate stays nearly constant below 40 to 60 000-ft range and is nearly equal to the intercept value. The intercept velocity can be evaluated at the same time the transfer impulse is evaluated. Thus, the pilot will know the intercept range-rate at initiation of the transfer.

Characteristics of Miss Trajectories

Consider now the range, range-rate profiles for the case when the primary system failed to establish the LEM on a collision course with the CSM. The results of such a failure are shown in the range, range-rate profiles of figure 3. Velocity errors were introduced into the intercept transfers of figure 2 to produce the miss trajectories. In case no. 1, errors were introduced at pericynthion to produce a

27 500-ft miss distance. The intercept velocity should be about 175 ft/sec. At 140 000-ft range, the velocity is only 150 ft/sec, therefore, the pilot should expect the range-rate to be increasing. At 80 000 ft the range-rate hits a maximum value of 155 ft/sec and starts to decrease. At this range, or shortly thereafter, the pilot knows he is missing the target.

In case no. 2, a 180° intercept, a velocity error was introduced at 140 000-ft range which caused a miss of about 28 500 ft. The expected intercept velocity for this trajectory was 97 ft/sec. At a range of 60 000 ft the range-rate dropped below this value and continued to decrease and a miss was indicated. Similarly, in case no. 4, the range-rate dropped below the intercept velocity at about 72 000-ft range with a negative slope and a miss was indicated. Thus, if the terminal relative range-rate becomes nearly constant at the expected value of range and range-rate, an intercept will result (fig. 2). If however, the range-rate drops significantly below this expected value, a miss will result (fig. 3).

Technique to Detect Miss Trajectory

In light of the characteristics of the above trajectories, the following technique can be formulated. By monitoring range and range-rate the pilot can detect a failure of the primary system to establish an intercept. The detection is at ranges large enough to allow transfer of the rendezvous task to an alternate system or for manual takeover.

Characteristics of Terminal Maneuvers

The second function of the primary system is to perform terminal rendezvous by re-establishing the intercept and reducing the terminal relative range-rate to a safe docking level whether on a miss trajectory or an intercept. This goal is accomplished according to a selected predetermined relative range, relative range-rate profile, that is, at a particular relative range the intercept is re-established with a reduced range-rate. If the first range is less than the miss distance, then the pilot would have to take action on the intercept as pointed out above, to get within the initiation range; that is, if the range-rate begins to decrease rapidly before the initiation range, then the initiation range will not be reached without a correction. The range, range-rate histories of some typical automatic terminal rendezvous maneuvers are shown in figure 4. In these cases, the rendezvous are performed off the following transfers: Numbers 1 and 4 of figure 2 and numbers 1 and 4 of figure 3. The miss distances are marked on the abscissa. The predetermined profile is also shown on the figure. Note that the misses are within the range for initiation of terminal rendezvous. Thus, if the second function of the primary system is performed without error, that is, an intercept and soft rendezvous is established, the range-rate will be a constant known value between braking maneuvers whether it is performed from an intercept transfer or a miss transfer. This is true of all correct terminal rendezvous trajectories.

Characteristics of Terminal Guidance Failure

The following case will illustrate a failure of the primary system in executing the terminal rendezvous maneuver. In figure 5, a range, range-rate profile of a nominal 50 000-ft to 80 nautical mile Hohmann transfer is shown. The transfer should have resulted in an intercept with a terminal range-rate of 97 ft/sec. However, a velocity error was introduced which resulted in the LEM missing the CSM by 21 050 ft as shown in the figure. The first range in the rendezvous profile is at 34 000 ft. Therefore, terminal rendezvous was initiated. However, the first correction at 34 000 ft to reduce the range-rate and establish the intercept was in error, and since the second correction point at 12 150 ft was never reached, a 17 000-ft miss resulted. However, since the range-rate did not remain nearly constant at the expected value, the pilot monitoring range-rate would have taken corrective action as shown on the figure at points A and B and an intercept could have been established at 12 150 ft. At point A the pilot's corrective action was still insufficient to establish intercept which was indicated by the range-rate monitor and a second correction was made at point B. (See reference 1 for manual technique.)

Technique to Monitor Terminal Maneuver

From the discussion of the characteristics of the terminal guidance maneuvers the following technique can be established. By monitoring range and range-rate the pilot can detect a failure of the primary system in performing the terminal rendezvous maneuver.

SUMMATION OF MONITORING TECHNIQUE

From the above discussion the following monitoring technique can be established for the entire rendezvous maneuver. If, before initiation of terminal rendezvous, the range-rate drops significantly below the expected terminal value predicted by the primary guidance system for a particular intercept transfer, then the transfer is missing the target. If, in the execution of the terminal rendezvous maneuver, the range-rate does not remain nearly constant at the reduced value for the intercept between maneuvers, then the primary system is in error and the rendezvous will not be successful. The display used by the pilot to monitor the primary system could be the one illustrated in figure 6. The range and range-rate are shown here in feet and feet per second, respectively. The shaded region of the range-rate display is the closure or negative range-rate region. The range and range-rate displayed are those of case no. 1 of figure 3. At 80 000 ft the range-rate is 155 ft/sec and the pilot should realize that he is missing the target since at this time the range-rate will start to decrease. The displays would be equipped with scale switches so that the range and range-rate can be read accurately in the region of the terminal maneuvers. Thus, by monitoring range and range-rate the pilot can detect errors in the intercept transfer or the execution of the terminal rendezvous maneuver. In this manner the pilot can determine whether or not manual takeover of rendezvous is necessary.

CONCLUDING REMARKS

The foregoing analysis of typical LEM-CSM rendezvous trajectories has led to the establishment of a technique for monitoring the primary rendezvous guidance system on board the LEM spacecraft. On a relative range, relative range-rate profile of the intercept transfers, the range-rate becomes nearly constant at some known range after an intercept has been established. Moreover, if the terminal rendezvous maneuver is executed properly, the range-rate will again be nearly constant at the value of the range, range-rate rendezvous profile. Thus, to insure that the primary guidance system is functioning properly the pilot need only monitor range and range-rate between the two spacecrafts. In this manner, he can determine if manual takeover is necessary. The fact that a constant range-rate during the terminal phase of the rendezvous maneuver will insure an intercept is a firm basis for a manual backup guidance technique for terminal rendezvous, in case of a malfunction in the primary guidance system.

REFERENCE

1. Stull, Paul J., and Price, Charles R.: The Effect of Line-of-Sight Rate Tolerance on a Proposed Backup Guidance Technique for LEM-CSM, MSC Internal Note 65-EG-6, Feb. 1, 1965.

A-B Launch from lunar surface
B-C Parking orbit
C Initiation of Transfer
D LEM-CSM Intercept

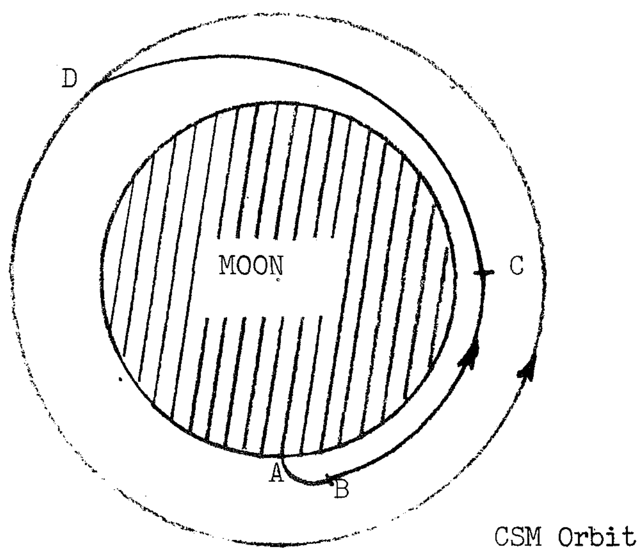

Figure 1.- LEM-CSM rendezvous procedure.

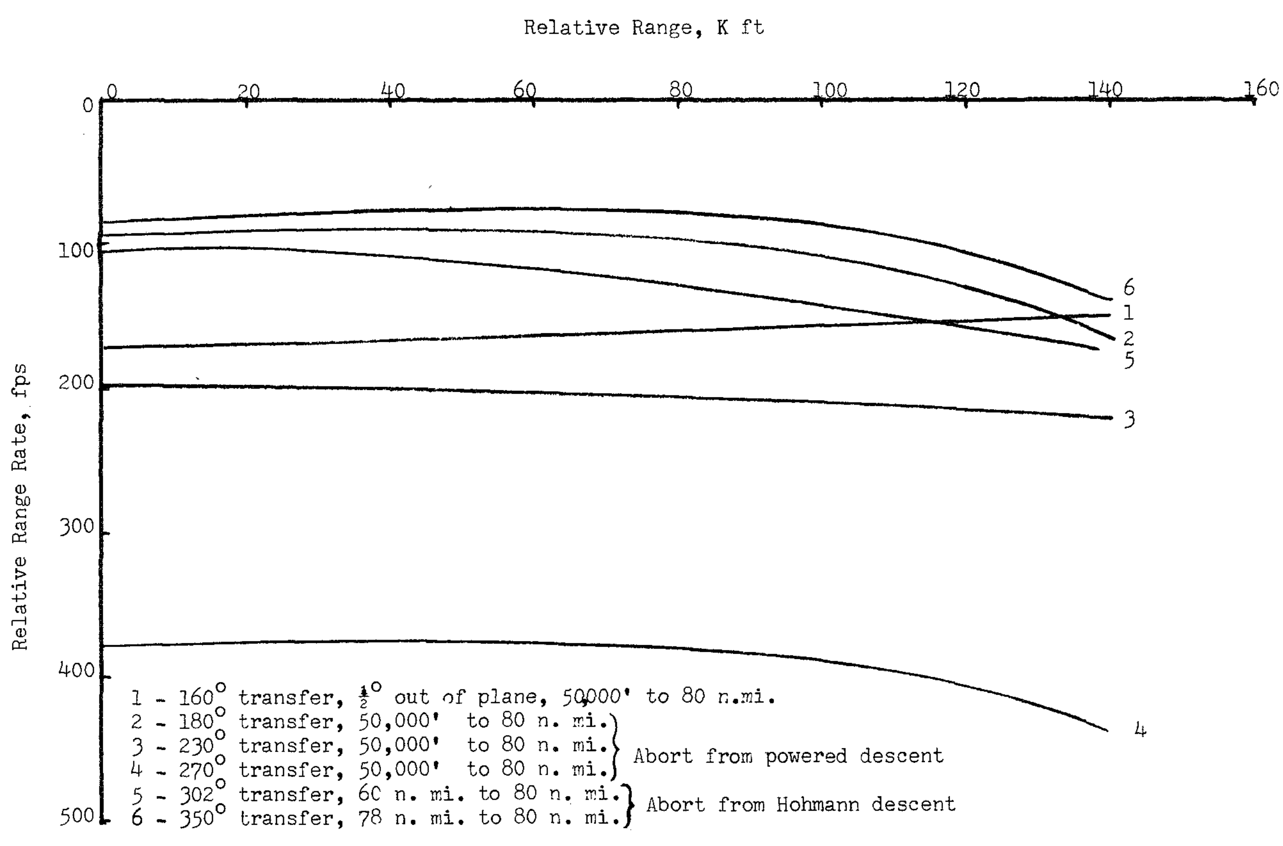

Figure 2.- Uncorrected intercept transfers.

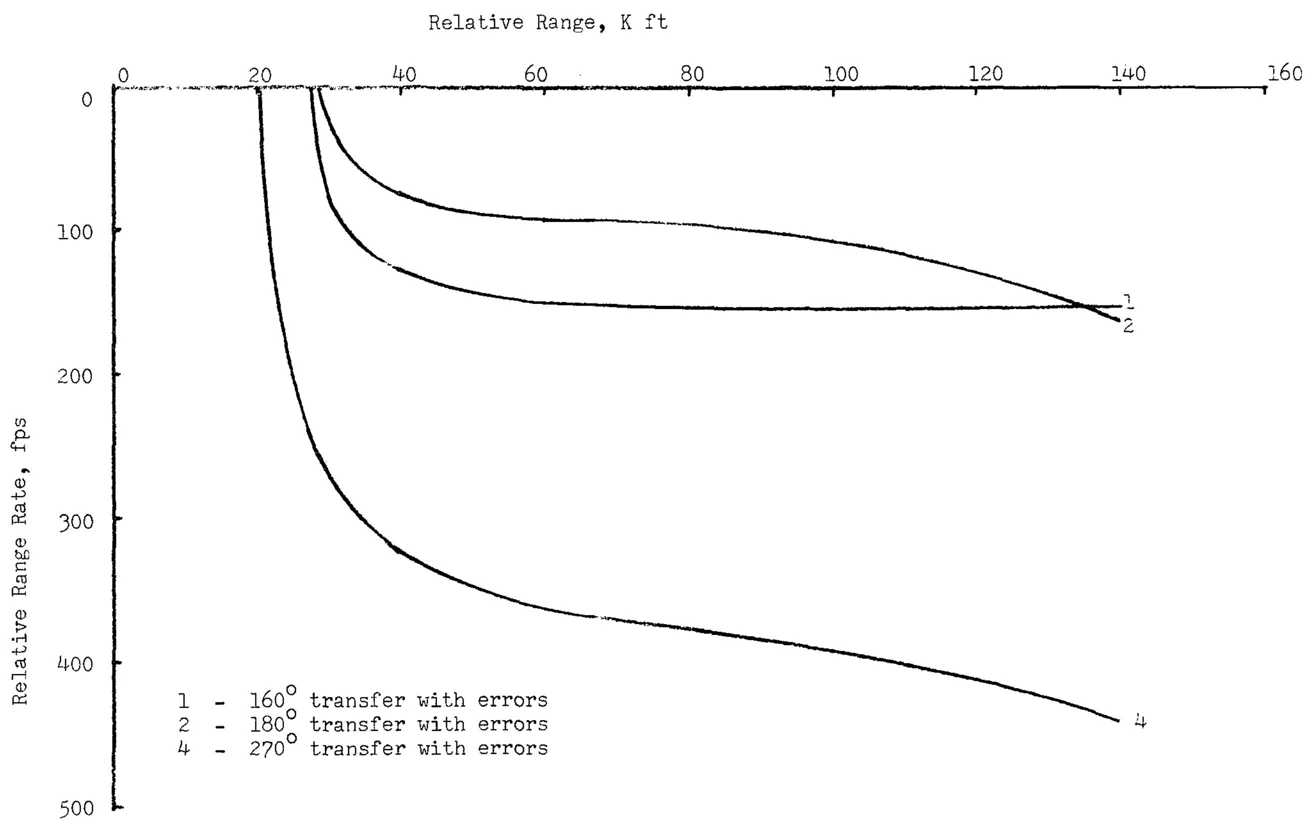

Figure 3.- Uncorrected miss transfers.

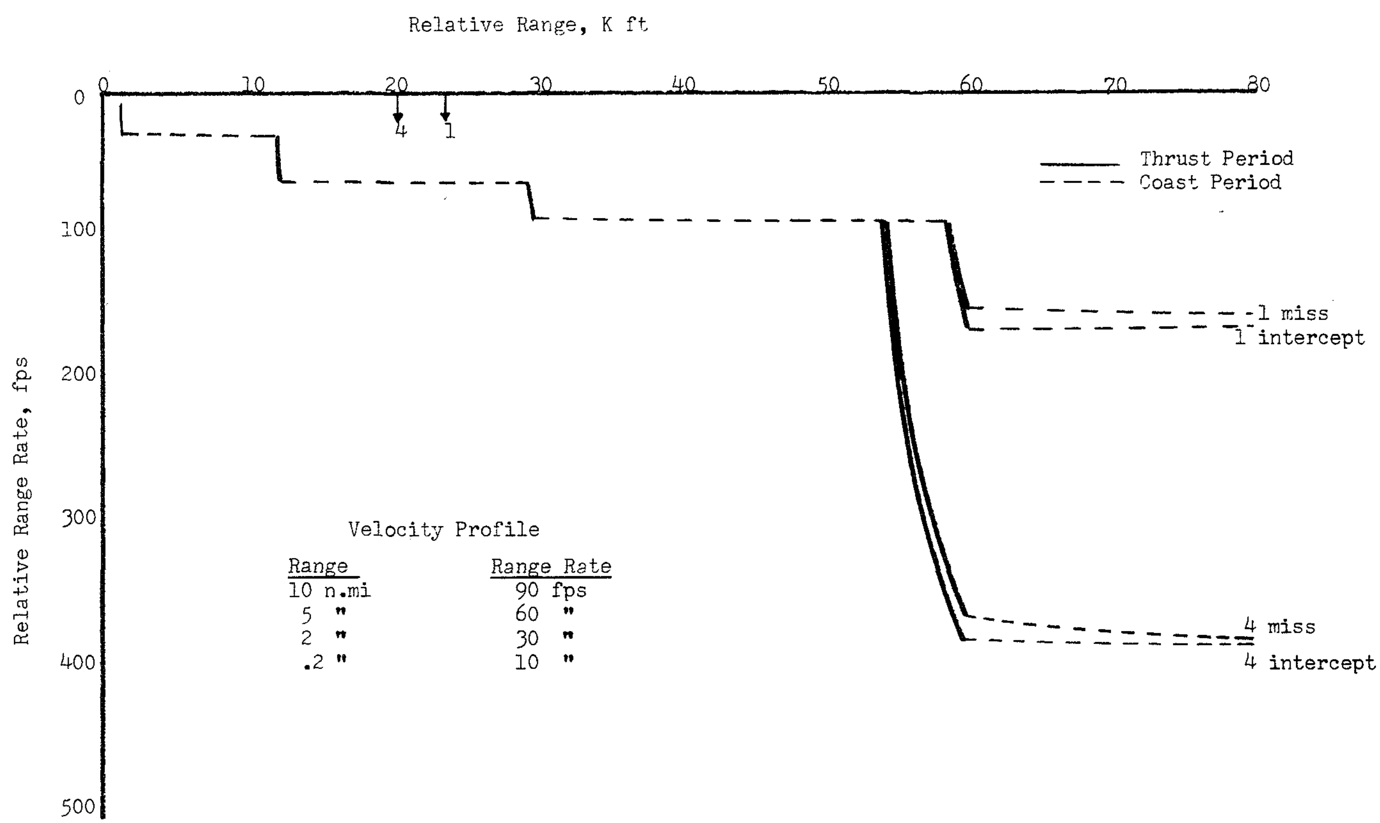

Figure 4.- Rendezvous trajectories using primary guidance system.

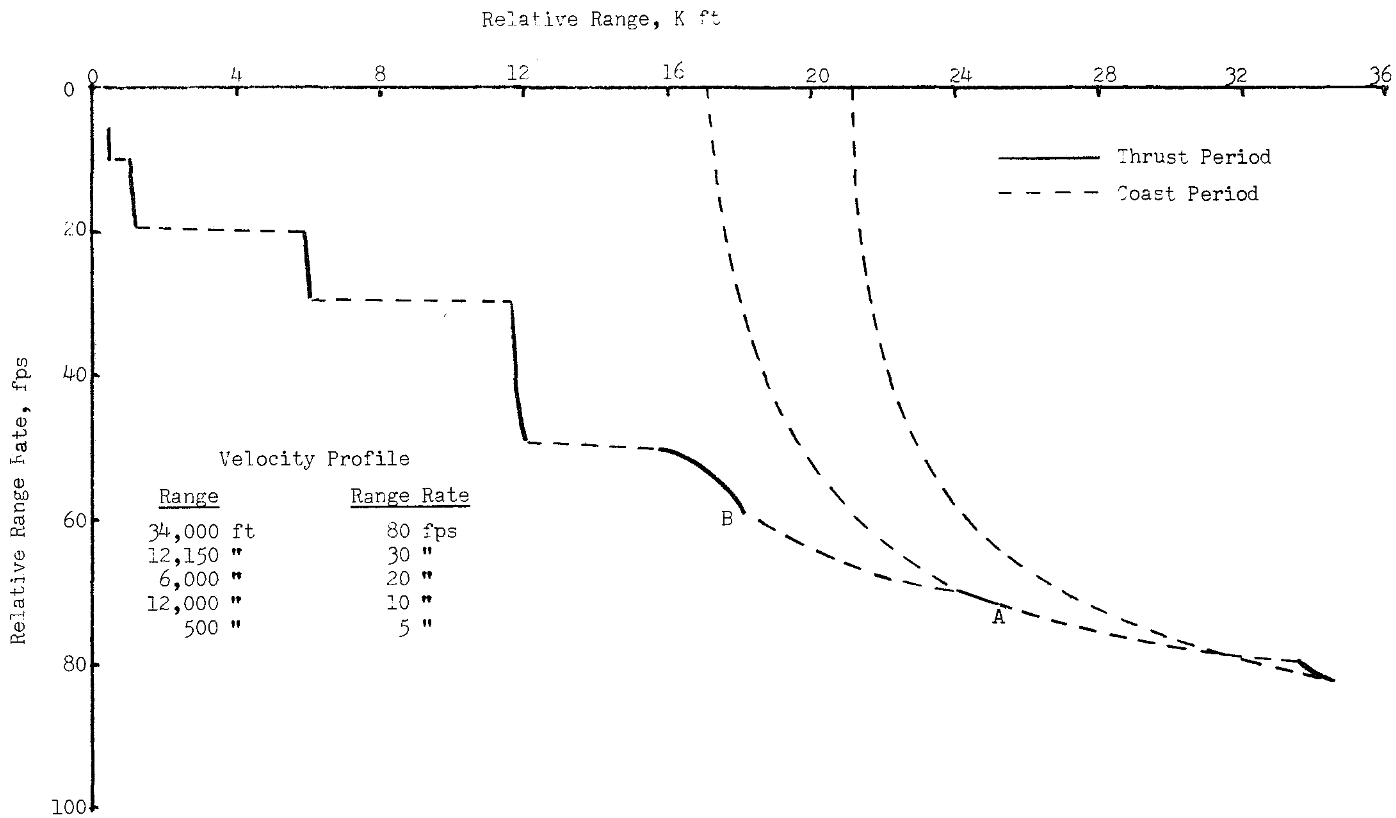

Figure 5.- Rendezvous trajectory from a miss transfer using monitored primary system.

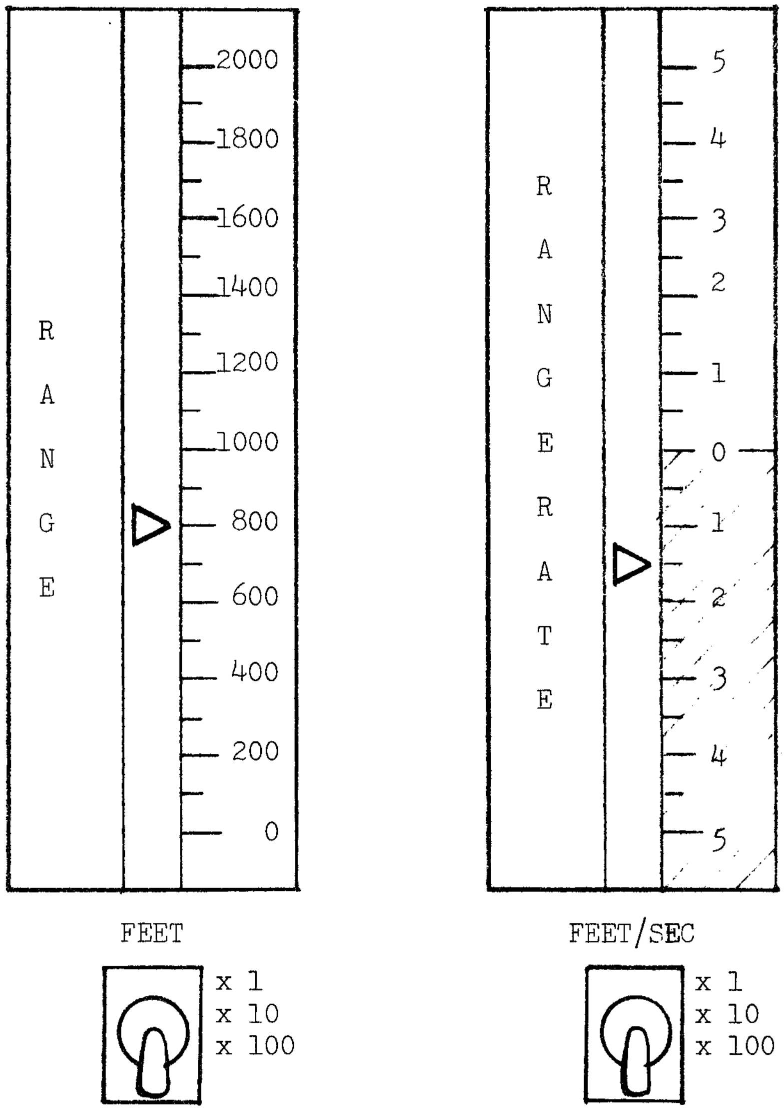

Figure 6.- Range and range-rate display.